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Effects of Hydraulic Stimulation on Coalbeds and Associated Strata

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8260

Effects of Hydraulic Stimulation on Coalbeds and Associated Strata

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UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

BUREAU OF MINES

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EFFECTS OF HYDRAULIC STIMULATION ON COALBEDS AND ASSOCIATED STRATA

by

Curtis H. Elder[1]

ABSTRACT

In studies conducted by the Bureau of Mines, two test areas were hydraulically stimulated and exposed by mining: One in the Pittsburgh coalbed at the Vesta No. 5 mine, Washington County, Pa.; and one in the Illinois No. 6 coalbed at the Inland mine, Jefferson County, Ill. Induced fractures were contained totally within the coalbed with no adverse effect on the stability of associated rock strata. Induced fractures were vertical and were propagated normal to the direction of least residual tectonic stress. Gas production was increased fivefold to twentyfold by hydraulic stimulation.

INTRODUCTION

Hydraulic stimulation is a process developed by the oil industry for increasing productivity of a reservoir. Vertical test holes drilled in advance of mining have been hydraulically stimulated to degasify the coalbed more efficiently by increasing the gas flow. Increases of fivefold to twentyfold have been achieved (1-2).[2] The procedure consists of inducing fractures in a coalbed by applying hydraulic pressure with controlled injection of gelled water and propping sand. The fractures are propagated several hundred feet into the coalbed by pumping large volumes of the treatment fluid. Flow characteristics of the fluid and size of propping sand were found to affect the length and width of the induced fracture. The propped fracture forms an open, permeable path of high-flow capacity to the borehole.

In spite of its advantages, concern for maintaining the integrity of mine roof and floor has deterred coal mine management from applying hydraulic stimulation to increase gas flow from vertical degasification boreholes in advance of mining. This concern motivated the Bureau of Mines to investigate the effects of the stimulation treatment on coalbeds and the rock strata that form the roof and floor of the mine in several areas of the United States.

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[2]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

Hydraulically stimulated areas have been exposed by mining at test sites in the Pittsburgh and Illinois No. 6 coalbeds, providing the opportunity for observation underground. This paper documents the hydraulic stimulation procedures and subsequent underground observations of the effect on these coalbeds and associated roof and floor rock strata.

ACKNOWLEDGMENTS

I thank Herbert Steinman, chief engineer, and Bob Thomas, mine superintendent, Vesta No. 5 mine, Jones & Laughlin Steel Corp., California, Pa.; and Dick Shockley, engineer, Inland mine, Inland Steel Co., Sesser, Ill., for providing rights-of-way, mine data, and access to the mines, and especially for their assistance in achieving the goals of this investigation. Thanks are also due to Ray Wenzel, assistant division engineer, and Halliburton Services Co., Pittsburgh, Pa., for their help in designing and implementing the stimulation treatment.

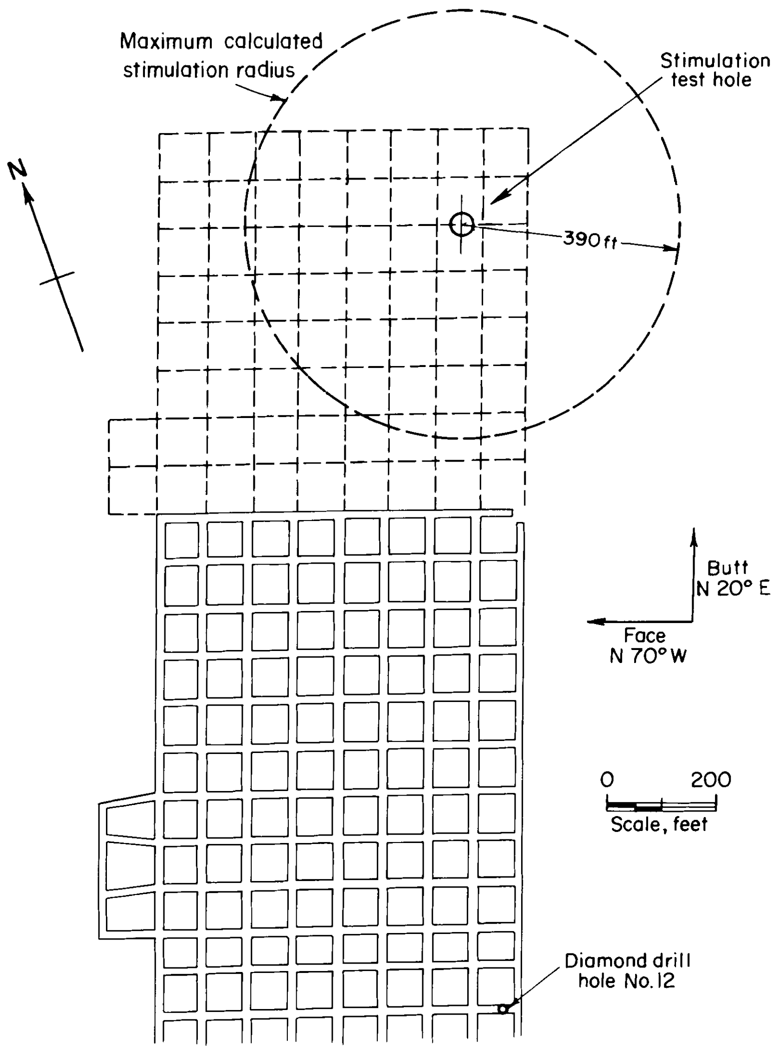

FIGURE 1. - Location of hydraulic stimulation test hole in relation to mine development at time of stimulation.

PITTSBURGH COALBED, WASHINGTON COUNTY, PA.: TEST HOLE USBM NO. 4

Drilling and Hydraulic Stimulation

To determine the effect of hydraulic stimulation on the Pittsburgh coalbed and the overlying rock strata, a test hole was drilled at Vesta No. 5 mine in Washington County, Pa. The hole was located 500 feet ahead of an active developing section of the mine (fig. 1).

Drilling began April 10, 1974, with a rotary drill rig. Twenty feet of 7-5/8-inch surface casing was set for control of shallow water-bearing strata. A 6-1/4-inch hole was then drilled to a total depth of 597 feet. The Pittsburgh coalbed was reached at 588 feet. Six feet of the coalbed was drilled, and the hole terminated three feet below the coalbed.

The test hole penetrated a series of interbedded shales, limestones, sandstones, and coalbeds in the Monongahela and Dunkard Group sediments of the Pennsylvanian System. The drill site lies near the axis of a small synclinal fold on the flank of the Amity anticline (fig. 2). In the vicinity of the borehole, the Pittsburgh coalbed is immediately overlain by a thin shale (draw slate) and underlain by calcareous claystone.

A plan was designed to hydraulically stimulate the coalbed within a 500-foot radius from the test hole so that the induced fractures would not intercept mine entries (fig. 1).

Table 1 shows the estimated results expected for the stimulation treatment for volumes of 5,000 and 10,000 gallons of gelled water (3). Design 1 was chosen in order to contain the fracture within the area of unmined coal. The propping sand was treated with a baked-on fluorescent dye for easier recognition in the mine when mining intercepted the fracture.

TABLE 1. - Designs for stimulation of borehole USBM No. 4, Washington County, Pa.

	Design 1	Design 2
Production......................fold increase..	10.7	16.9
Total volume.............................Mgal..	5.0	10.0
Pad volume...............................Mgal..	2.0	2.0
Propped fracture length..................feet..	219	411
Propped fracture height....................do...	5.0	5.2
Viscosity........................centipoises..	4	4
Fracture width.......................inches..	0.22	0.25
Propping sand.................100-pound sacks..	35	90
Created length[1]........................feet..	387	662

[1]Maximum length of induced fracture created with and without sand prop.

On April 17, 1974, the well was treated through 2-3/8-inch-diameter high-pressure tubing. An open hole packer in the tubing string was set at 585 feet in a hard formation 3 feet above the coalbed. The treatment used 7,300 gallons of water containing 550 pounds of guar gum, 3,000 pounds of 10- to 20-mesh fluorescent-dye-treated sand followed by 500 pounds of 10- to 20-mesh regular sand.

Two thousand gallons of gelled fluid was injected into the coalbed to fill all spaces in the coalbed around the borehole and initiate the fracture. The formation broke at 500 psig. The induced fracture was propagated into the coalbed with an injection rate of 10-1/2 bpm. The pad volume was followed with successive injections of 1,300 gallons of sand-laden treating fluid at 1/4 ppg (pounds per gallon) sand concentration, 650 gallons at 1/2 ppg, 1,750 gallons at 3/4 ppg, and 1,350 gallons at 1/2 ppg sand concentration. The tubing was cleared of sand with 250 gallons of treating fluid. An injection rate of 10-1/2 bpm was maintained during treatment at an average injection pressure of 1,586 psig. A maximum injection pressure of 1,700 psig was reached (fig. 3).

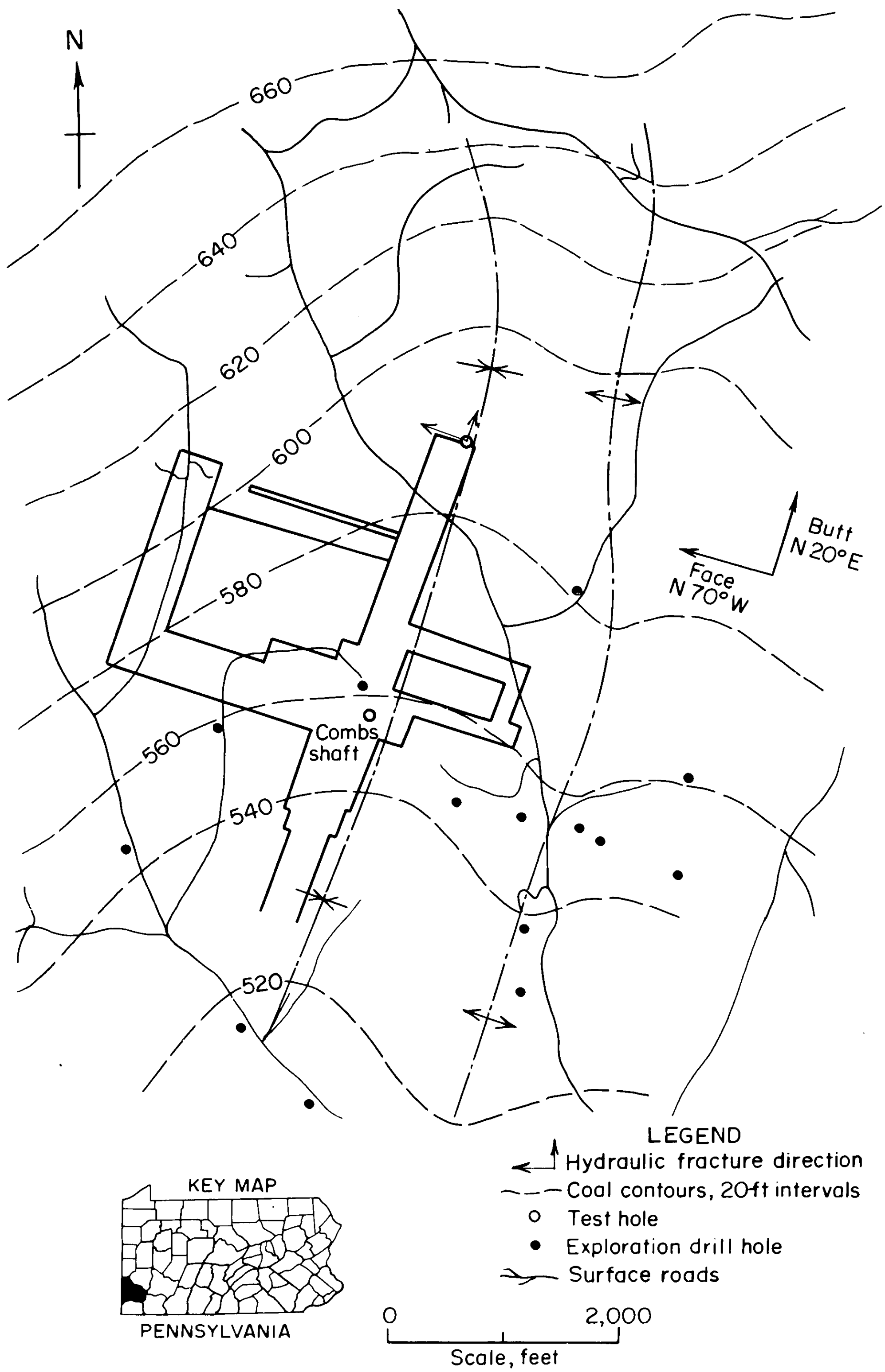

FIGURE 2. - Structure map contoured on Pittsburgh coalbed showing location of Vesta No. 5 mine and test hole.

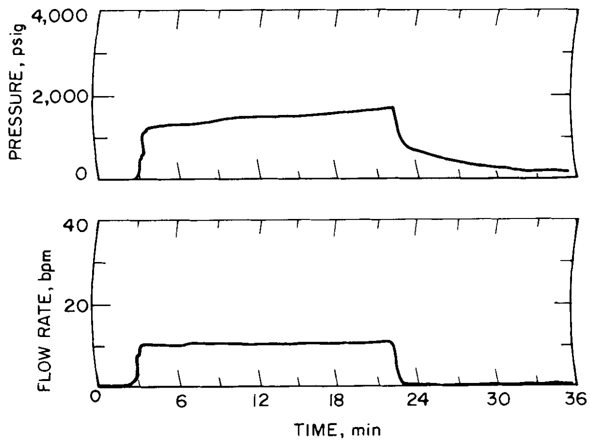

FIGURE 3. - Pressure and flow rate charts recorded during hydraulic stimulation.

Observations Underground

Mine entries closest to the borehole were monitored by Bureau and mining company engineers during the hydraulic fracture treatment. No evidence of gas or water emission was observed in the mine entries during the treatment. This indicates that the treatment remained within the design limits and did not create hazardous underground conditions. Ventilation air samples taken at regular intervals during and following treatment showed no increase in gas emission into the mine.

On June 12, 1974, the induced fractures were intercepted by mining. Twenty feet of vertical sand-propped fracture was mapped along the face cleat direction west of the borehole. The sand-filled fracture ranged from one-eighth to one-half inch in width, extending from the draw slate at the top of the coalbed to the mine floor. There was no evidence that the fracture extended into the roof or floor rock (figs. 4-6). Wide vertical fractures were propagated to the north of the borehole along the butt cleat direction. These fractures were 1/2 to 2-1/2 inches in width and were packed with the propping sand (figs. 7-8). They extended from the base of the draw slate to the floor. Again, no evidence was found to indicate that the induced fractures along the butt cleat direction penetrated the roof (fig. 9) or floor rock.

Roof stability was not affected by the induced fracture, and mining advanced normally through the treated zone. The dyed propping sand fluoresced under ultraviolet radiation, making very thin sand-filled fractures more apparent; however, the use of dyed propping sand was not needed to locate the fractures. It is estimated that the fractures extended 35 feet or more into the coalbed in the butt cleat direction. The fractures were wider than expected, averaging 2 inches in width. The greater width of the fractures was caused by the use of a heavily gelled treating fluid (75 pounds of guar gum per 1,000 gallons); a less viscous fracture fluid (20 pounds of guar gum per 1,000 gallons) would have created a thinner fracture, propagating deeper into the coalbed. Approximately 35 cu ft of fracture volume was created, which was filled with 35 cu ft of propping sand.

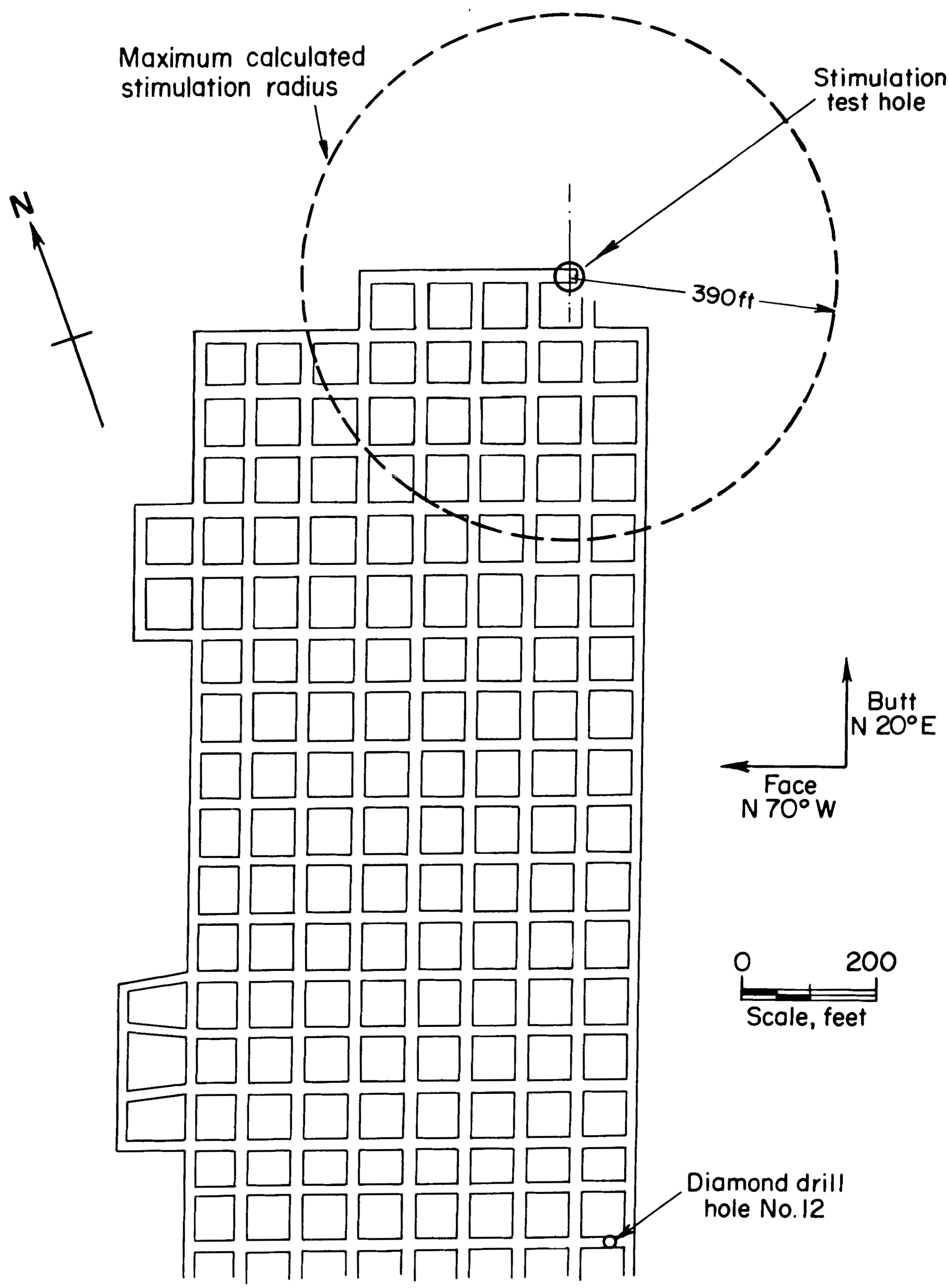

FIGURE 4. - Mine development at time the hole was intercepted.

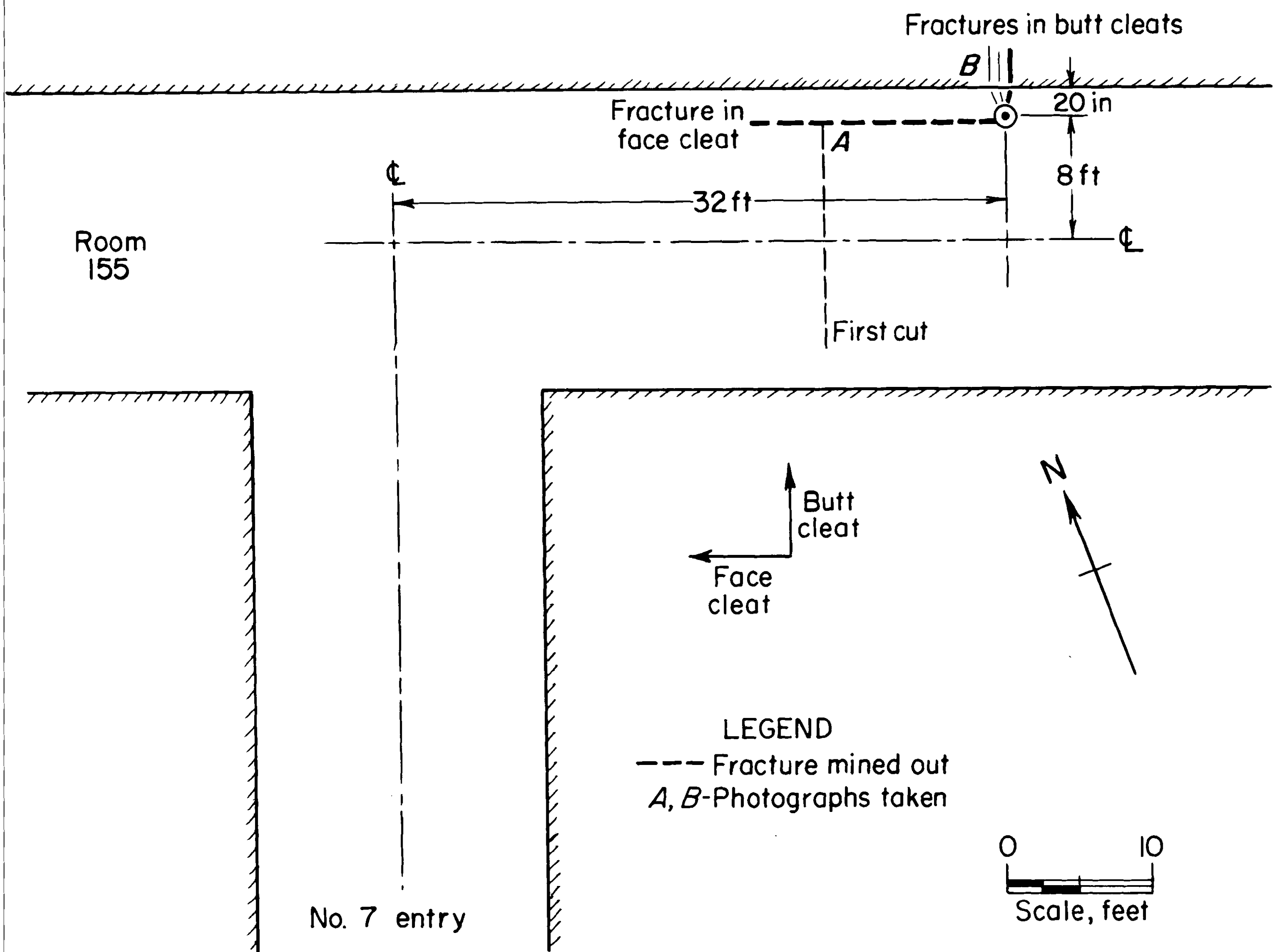

FIGURE 5. - Induced fracture orientation relative to mine entry development.

FIGURE 6. - Induced fracture in face cleat of Pittsburgh coalbed. Note termination of fracture at draw slate.

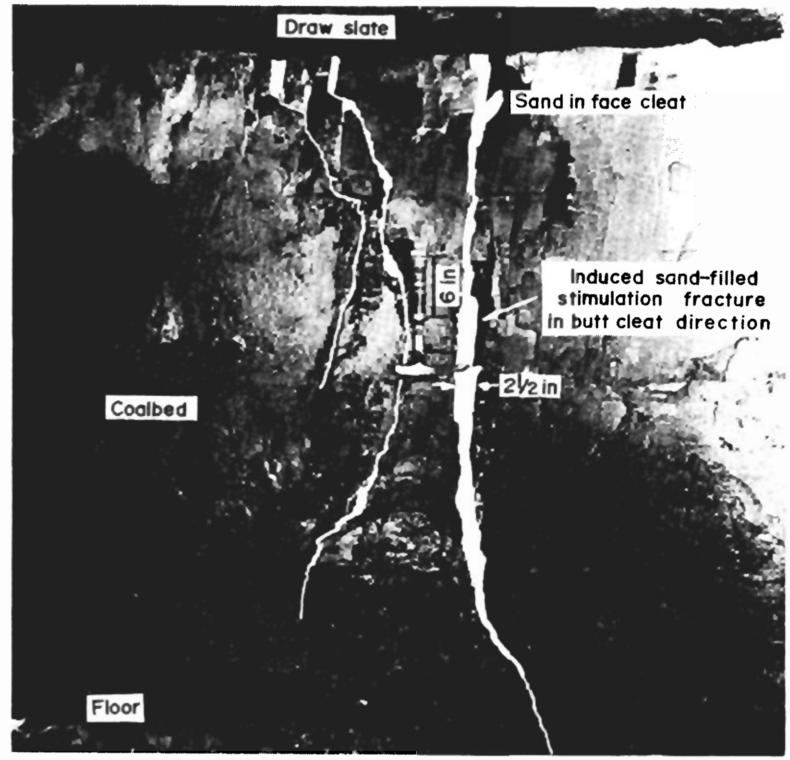

FIGURE 7. - Induced sand-filled fractures in butt cleat direction in Pittsburgh coalbed.

FIGURE 8. - Detail of induced fracture in middle of Pittsburgh coalbed at maximum width.

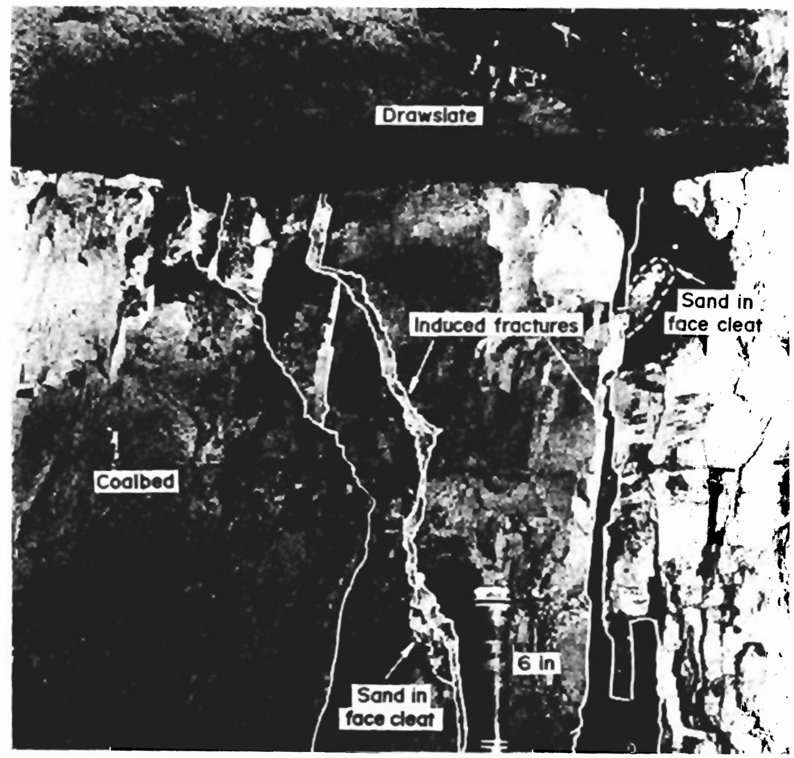

FIGURE 9. - Detail of induced fracture terminating at draw slate or rock strata overlying coalbed. The fracture does not penetrate overburden rock.

FIGURE 10. - Induced fracture after 2 years of exposure in mine.

The borehole and induced fracture site in the mine were inspected 2 years after treatment to observe long-term effects of stimulation on the roof strata and coal rib. No deterioration of roof or floor strata was evident. In addition, no spalling was observed along the roof or coal rib (fig. 10).

ILLINOIS NO. 6 COALBED, JEFFERSON COUNTY, ILL.: TEST HOLE USBM NO. 1NE

Drilling and Hydraulic Stimulation

A pattern of five degasification boreholes was drilled into the No. 6 coalbed at the Inland Steel Co. mine, Jefferson County, Ill. The holes were drilled during June 1972. The 9-inch-diameter holes were drilled with a rotary drill and cased with 7-inch-outside-diameter steel casing to within a few feet of the top of the coalbed. The northeast corner hole, No. 1NE of the pattern, was selected for hydraulic stimulation (fig. 11). It was drilled to a total depth of 743 feet and penetrated 9 feet of the No. 6 coalbed.

The test hole was drilled through a series of interbedded shales, sandstone, limestones, and coals in the Bond, Modesta, and Carbondale formations of the Missourian and Des Moines series of the Pennsylvanian System. The drill site is on the southwest flank of the Illinois coal basin. The No. 6 coalbed is overlain by 18 feet of sandy shale and underlain by 1 foot of fire clay.

A hydraulic stimulation was designed that would induce a fracture within a 450-foot radius from the borehole, and thus totally contained within the coalbed. Table 2 shows the calculated results expected from three stimulation treatment designs for fluid volumes of 5,000, 12,000, and 15,000 gallons (3). Design 2 was selected for the stimulation treatment. The coalbed was stimulated through a 2-3/8-inch-diameter high-pressure tubing. A packer in the tubing string was set in the casing at a depth of 720 feet, with a tailpipe extending to the middle of the coalbed to a depth of 733 feet. Twelve thousand gallons of water was gelled with 240 pounds of guar gum to form a light

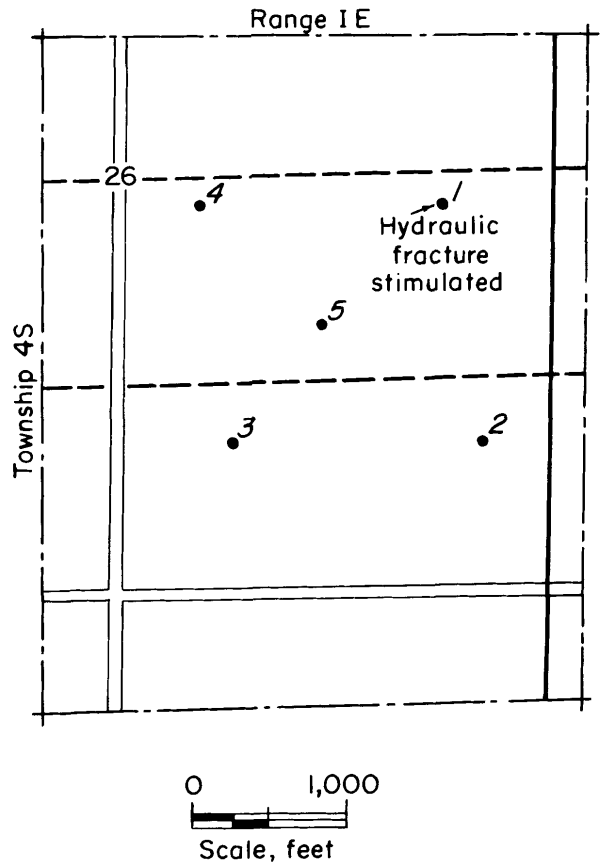

FIGURE 11. - Location of degasification borehole pattern for No. 6 coalbed, Inland mine, Jefferson County, Ill.

gel fluid. The gel fluid and 6,400 pounds of 10- to 20-mesh propping sand were used in the treatment.

TABLE 2. - Designs for stimulation of borehole USBM No. 1NE, Jefferson County, Ill.

	Design 1	Design 2	Design 3
Production......................fold increase..	5.5	7.5	8.0
Total volume.............................Mgal..	5.0	12.0	15.0
Pad volume...............................Mgal..	2.0	2.0	2.0
Propped fracture length..................feet..	140	305	391
Propped fracture height....................do...	6.9	6.9	7.1
Viscosity.........................centipoises..	6	6	7
Fracture width........................inches..	0.17	0.20	0.22
Propping sand.................100-pound sacks..	26	64	101
Created length[1]........................feet..	222	431	509

[1]Maximum length of induced fracture created with and without sand prop.

Two thousand gallons of gel fluid was injected into the coalbed to fill all spaces around the borehole and initiate the fracture. The formation broke at 1,000 psig. The fracture was propagated into the coalbed with an injection rate of 10 bpm. The following volumes of sand-laden gel fluid were successively injected into the coalbed: 3,000 gallons at 1/4 ppg sand concentration;

2,000 gallons at 1/2 ppg; 1,800 gallons at 3/4 ppg; and the final 3,200 gallons at 1 ppg. The average injection pressure was 900 psig, but a maximum injection pressure of 1,000 psig was reached (fig. 12). After treatment, the test hole was put back on gas and water production. The hole was not producing a significant amount of gas, perhaps owing to formation damage during drilling. Gas flow increased from 10 to 4,300 cfd. Testing of the No. 6 coalbed before stimulation had shown it to have a low gas content and low permeability, so the flow increase was substantial.

Observations Underground

The induced vertical fracture packed with propping sand was intercepted by mining in May 1974. The induced fracture was propagated in a direction of N 76° E from the borehole. It was mapped across four entries of the No. 11 Right entries off the West main entries of the mine (fig. 13). The induced vertical fracture did not follow the directions of the face or butt cleat; it followed a path subparallel to the axis of a small anticlinal fold on the flank of the coal basin (fig. 14). The stimulation created a single vertical fracture in the coalbed. A small amount of water drainage from the fracture alerted the operator of the continuous miner that the sand-filled fracture had been mined through. The fracture was mapped for 416 feet from the borehole. The sand-propped fracture extended vertically from the roof shale to a hard shale parting approximately 2 feet from the bottom of the coalbed. The fracture was 7 feet in height. It is normal practice in this mine to leave 1 foot of roof coal during mining to protect the shale overlying the coalbed from air, moisture, and weathering.

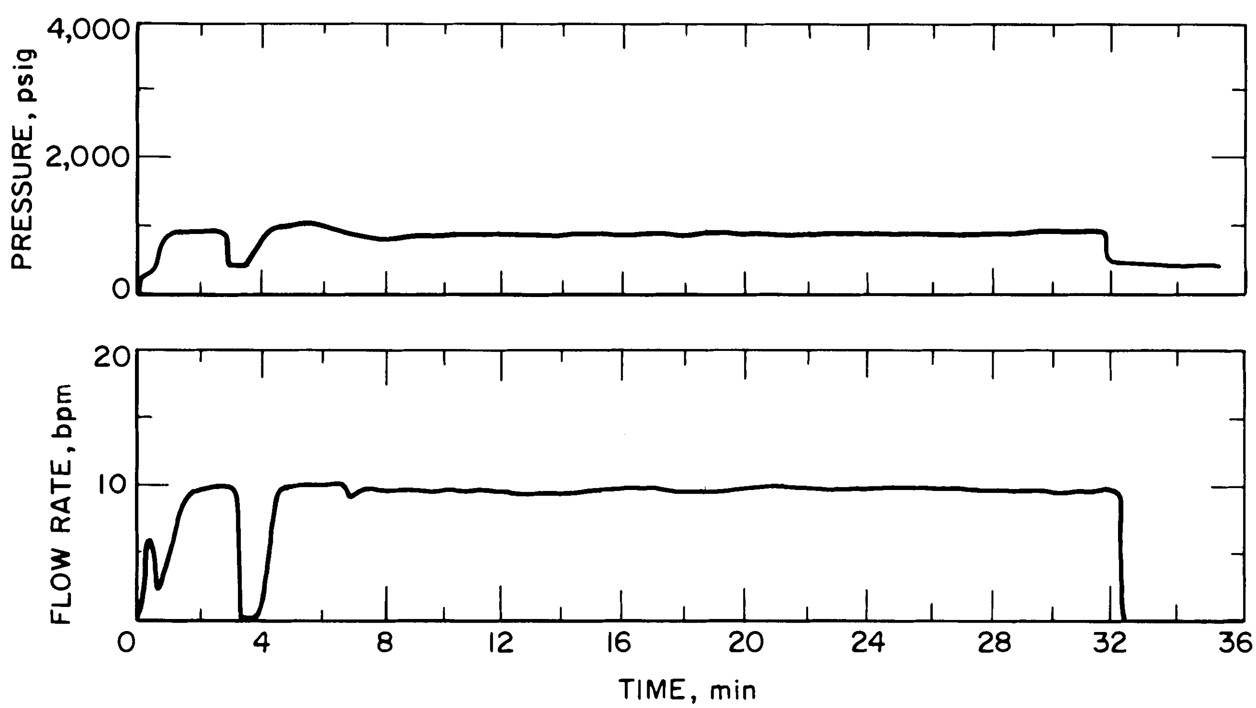

FIGURE 12. - Pressure and flow rate charts recorded during hydraulic stimulation.

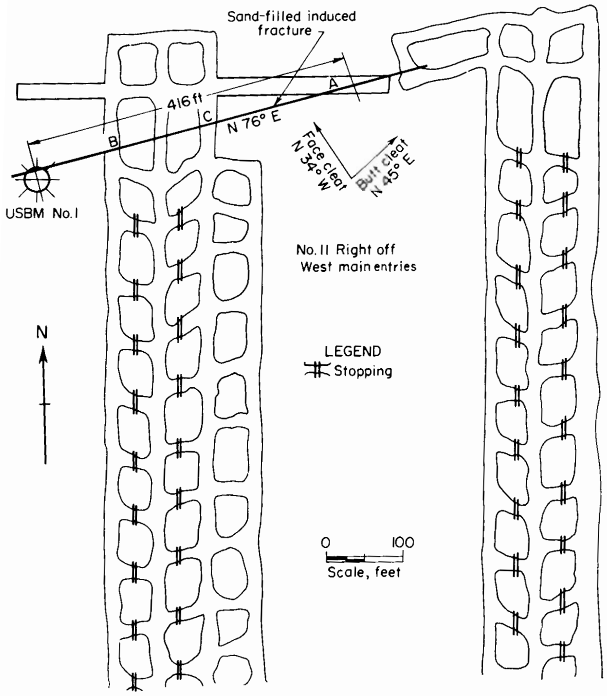

FIGURE 13. - Induced fracture orientation as related to mine entry development at Inland mine.

The fracture could be readily traced across the entries of the roof coal. It ranged from one-eighth to three-eighths inch in width, averaging approximately one-quarter inch (figs. 15-18). The sand-propped fracture did not extend into the roof or floor. The roof coal and rock remained stable in all the entries intersecting the fracture. Mining developed normally through the stimulated areas. Mine engineers noted a reduction in gas emission into the mine in the test area resulting from a long period of degasification prior to mining. Approximately 61 cu ft of fracture volume was created which was filled with sand. Sixty-four cubic feet of sand was used during the treatment. The 3-cu-ft difference can be attributed to sand that settled in the borehole. The excess sand was removed from the borehole immediately after treatment.

The site of the induced fracture exposed by mining was inspected 2-1/2 years after stimulation to assess the long-term effects of weathering on the roof strata along the trace of the fracture. No deterioration of roof or floor strata was evident.

The roof along the east-west bleeder entry at point A (fig. 19) had remained stable. There had been no spalling of roof or coal rib along the trace of the induced fracture (fig. 20).

At points B and C (fig. 19) in the north-south entries where the induced fracture was in close proximity to retreat mining, the roof remained stable until the coal in the adjacent pillars was mined out (fig. 21). Roof fall resulting from pillar extraction did not reflect any weakness in the roof

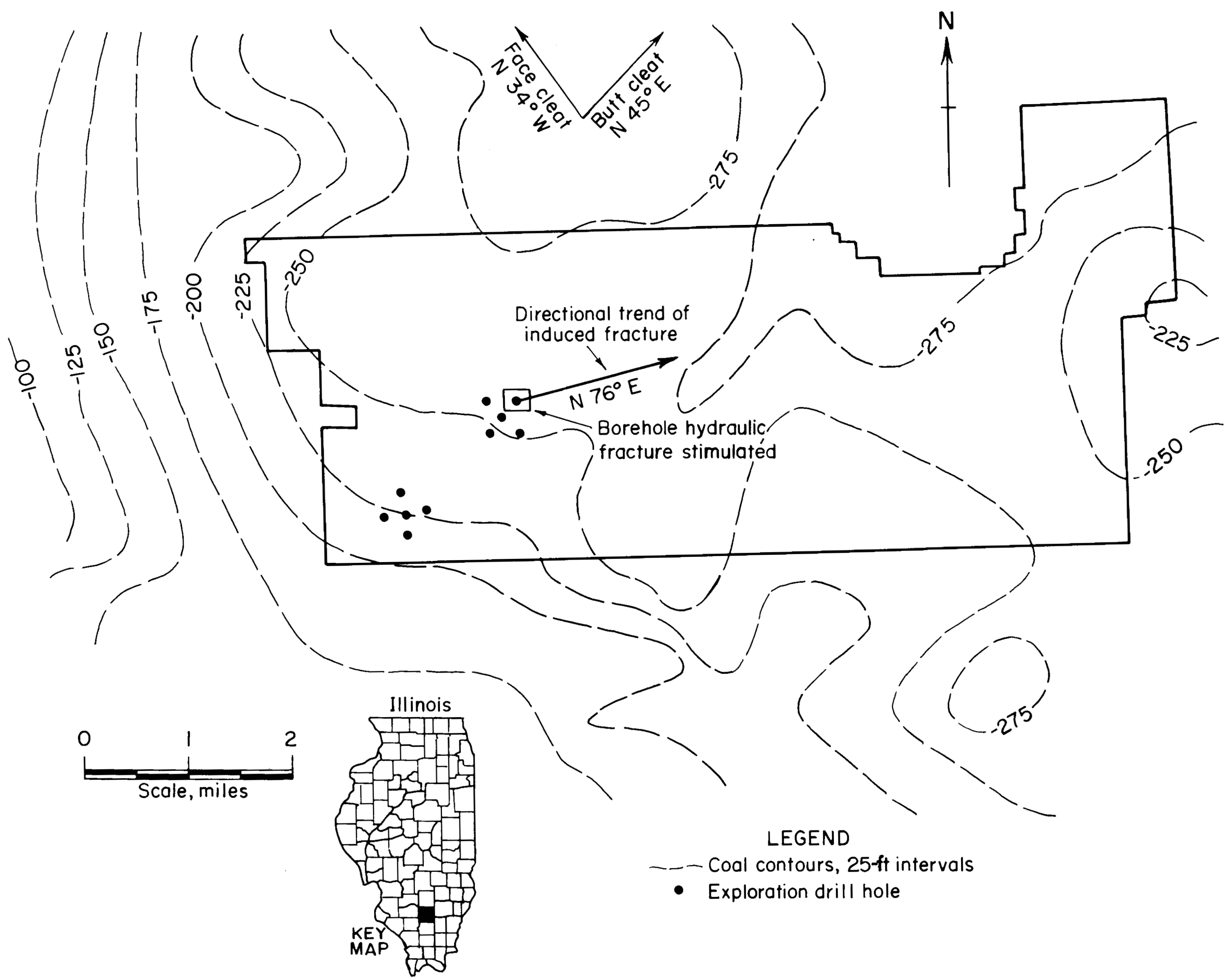

FIGURE 14. - Geologic structure map of No. 6 coalbed contoured on No. 6 coalbed, showing directional trend of induced fracture.

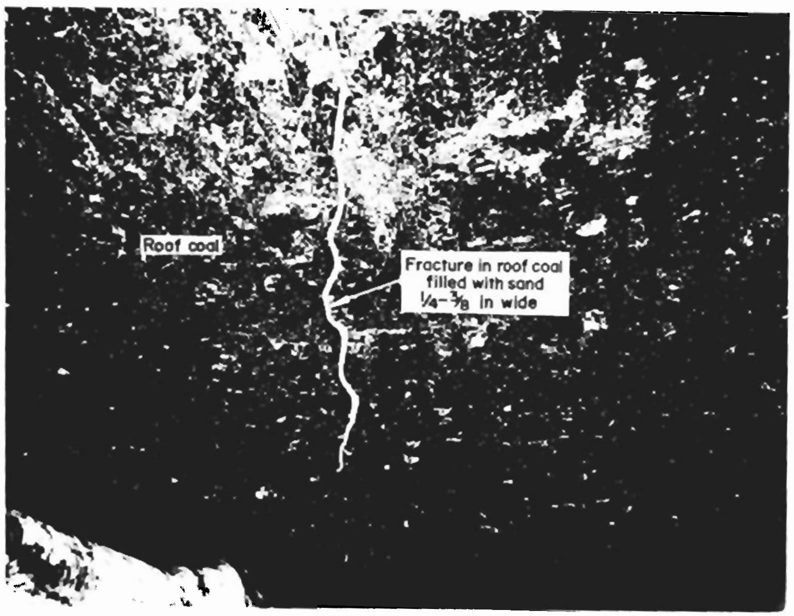

FIGURE 15. - Trace of sand-filled induced fracture in roof coal of mine entry of Inland mine at point A on figure 13.

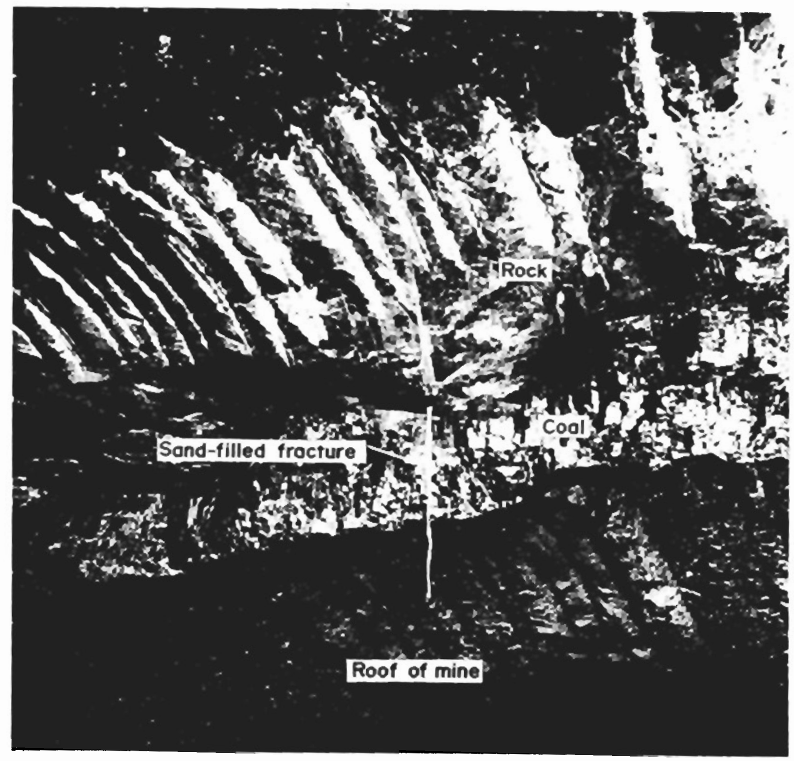

FIGURE 16. - Detcil of induced fractures in roof coal and termination of fracture at rock strata overlying coalbed at point A on figure 13.

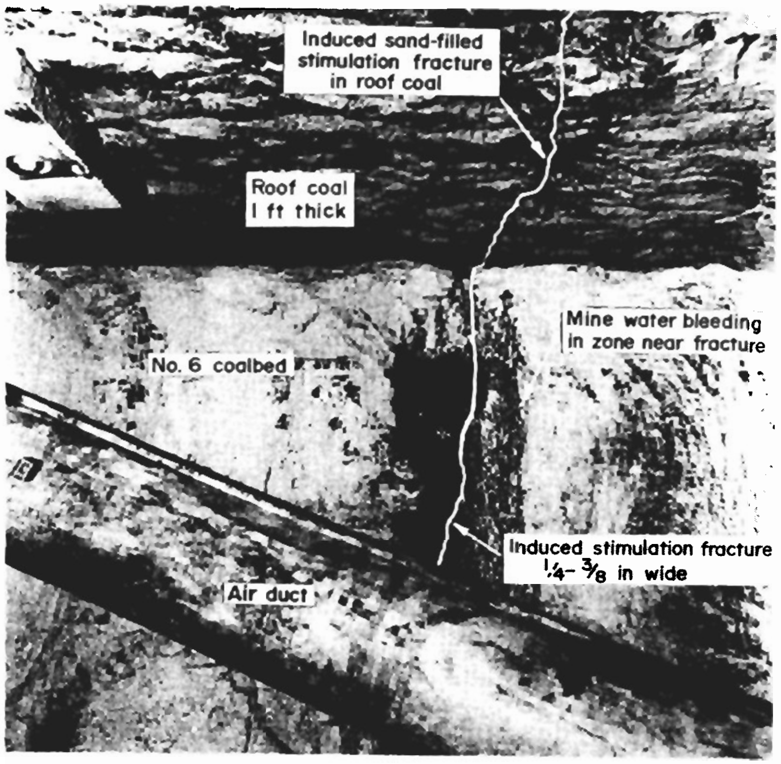

FIGURE 17. - Sand-filled induced fracture in rib and roof coal at point C on figure 13.

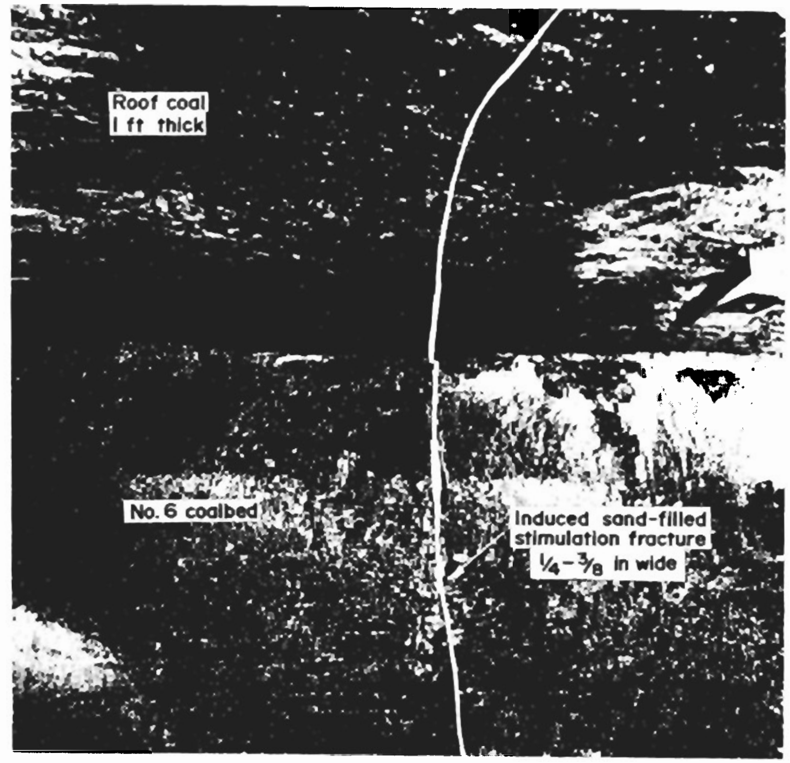

FIGURE 18. - Sand-filled induced fracture in rib and roof coal at point B on figure 13.

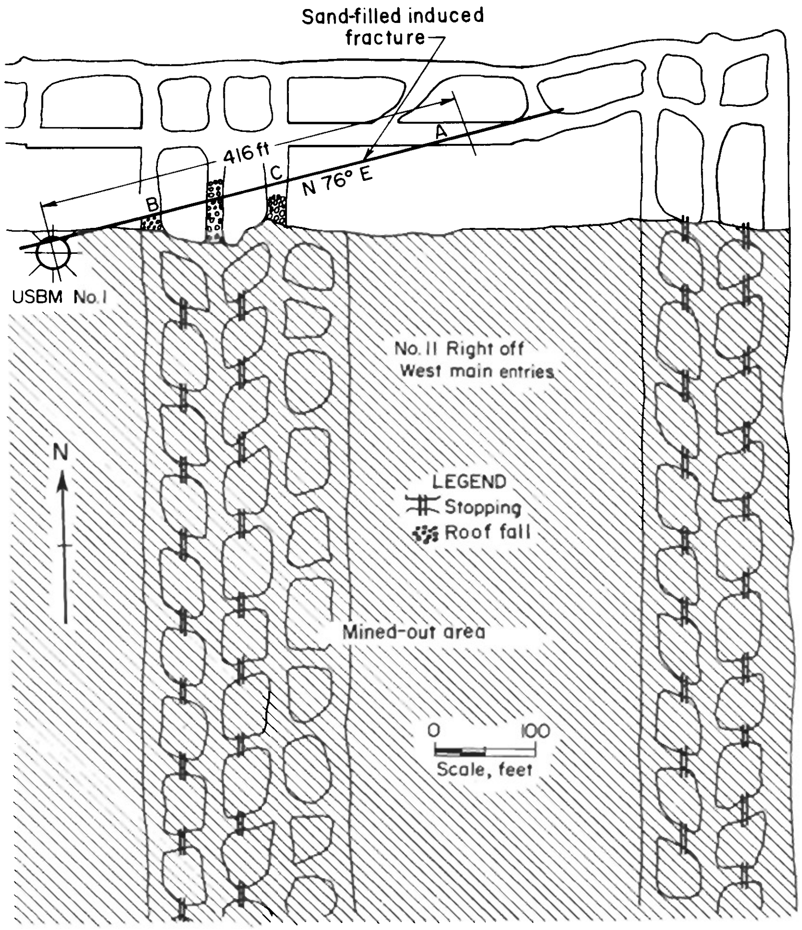

FIGURE 19. - Location of induced fracture in bleeder entry after the area was mined out.

FIGURE 20. - Induced fracture after 2-1/2 years of exposure to mine atmosphere at point A on figure 19.

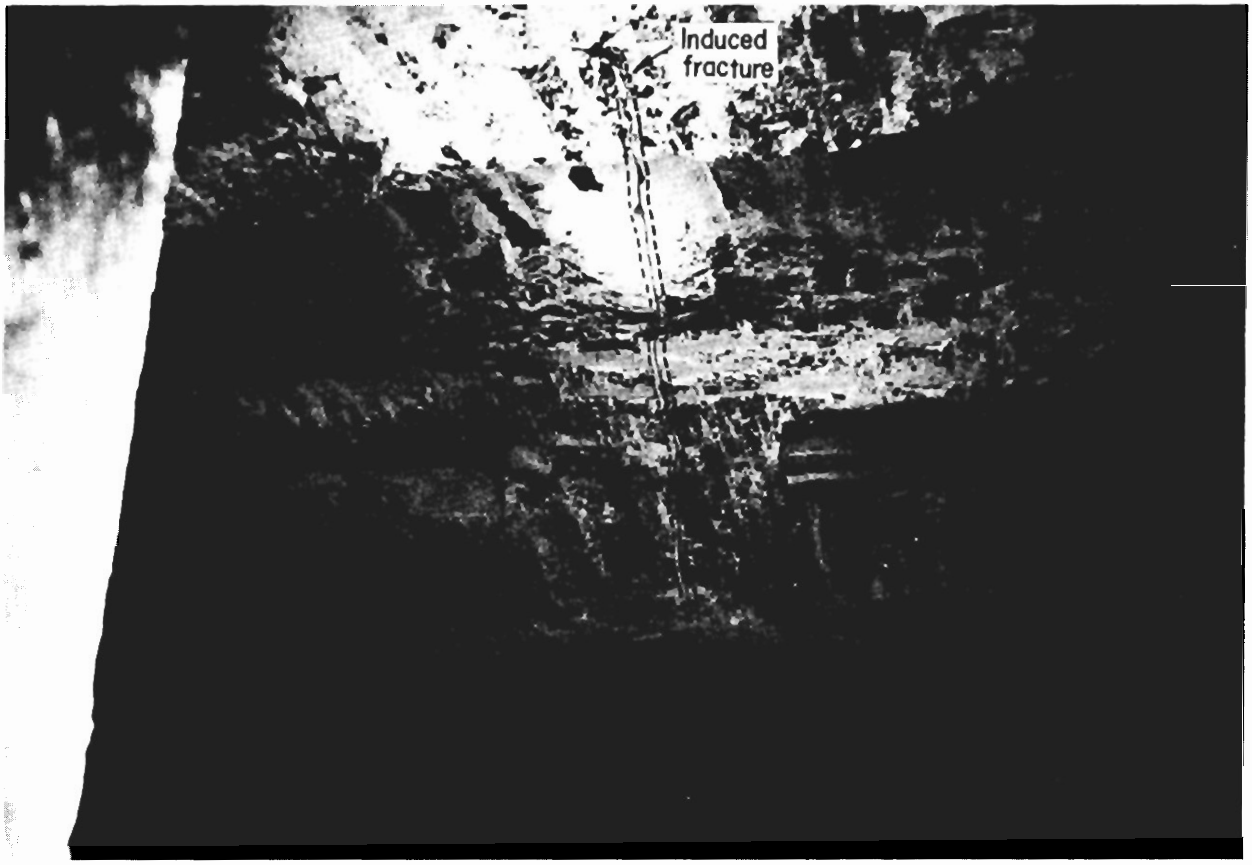

FIGURE 21. - Induced fracture after 2-1/2 years of exposure to mine atmosphere at point B on figure 19.

strata that could be related to the induced fracture. There was some evidence of fluid and sand intruding a few inches into a rock joint that crossed the induced fracture at point B (fig. 19). There was no evidence that this intrusion of sand and fluid in the rock joint impaired the roof or affected its stability.

DISCUSSION AND CONCLUSIONS

Observations at two hydraulically stimulated sites in coalbeds indicate that the resulting fractures are limited to, and contained within, the coalbed. There was no adverse effect on the stability of the overlying and underlying rock strata, or on mining operations.

Gas production from hydraulically stimulated degasification boreholes in coalbeds show a fivefold to twentyfold increase in sustained gas flow (2).

The direction in which the induced fracture may be expected to propagate into the coalbed is related to the tectonic stress pattern in the mine area.

The fracture may follow joint or cleat directions, or be oriented perpendicularly to the least horizontal force or along the path of least resistance (4).

The induced fractures observed were vertical. Widths ranged from one-eighth to one-half inch. Highly viscous fracture fluids tend to form wider fractures of up to 2-1/2 inches in width. These fractures tend to have a smaller radial extent. Less viscous fracture fluids were found to create longer fractures, thus a more efficient stimulation.

Periodic observations of exposed fractures produced by hydraulic stimulation have shown that no deterioration of roof and floor strata, or loss of coal rib stability occurred in the areas of induced fractures. The mine entries observed remained structurally safe more than 2 years after mine interception of induced fractures.

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